727. Utilization of advanced self-diagnostic functions implemented in frequency inverters for the purpose of the computer-aided identification of operating conditions

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Abstract. The article is a continuation of papers published in previous publications referred to the development of the Computer Control and Diagnostic System of Distributed Drives [1, 2, 3]. Authors of the paper focused on the group of frequency inverters coupled by the ProfiBus DP network, elaborated expert system and integrated control and diagnostic blocks placed in the PLC memory, at an angle of possibility of utilization of integrated selfdiagnostic algorithms of frequency inverters to the implementation in the Computer Control and Diagnosis System of Distributed Drives (CCaDSoDD) system. The article includes also an analysis of potential possibilities of utilization of embedded functions and restrictions connected with accepted assumptions.

Keywords: self-diagnostic functions, frequency inverters, diagnostic inference.

Introduction

A design, an implementation and an operation of machines without taking into consideration aspects related to the monitoring of operating conditions and planning of the duty, is not possible in applications taking advantage of mechatronic devices. A noticeable progressive development of mechatronic equipment focuses to an expansion of internal algorithms and self-diagnostic functions. In the most of practical applications a user or a designer exclude functions which could be very useful at the stage of designing, implementation or exploitation of technical systems. Described situation results from producers appointment. A lot of manufacturers represent a position consistent with an economic strategy (besides selling exist also very powerful branch contains service activities). A successive reason is connected with safety standards, specified requirements defined by restrictions related to the assurance of operational safety.

Field of studies

Authors of this article have taken into consideration a model of frequently used application like group of distributed drives. An example of frequency inverters with electric motors and toothed gears or gear-motors is a very interested area coupled many mechatronics devices.

Usage of Programmable Logic Controllers and distributed drives equipped in industrial networks interfaces is a common case in industrial applications. PLCs popularity results from a fact that exchanged data most often have the status of control commands.

The practical implementation of presented method has been based on the laboratory stand designed for investigation of the distributed drives system. A scheme of described system is presented in Figure 1. Data processing tools are necessary to extract useful information from the monitored system. Most often identification is possible only with dedicated software, but the authors make an attempt to elaborate the authorship Computer Control and Diagnosis System of Distributed Drives with the integrated expert system.

The discussed solution provides the grounds for designing of the integrated diagnostic and control system. The CCaDSoDD system enables the control of the states of the PLCs, actuators and industrial sensors without embarrassment into the operation of the distributed system, and a simultaneous running of other software connected with actuators or control units.

The basic assumption of the decentralized system, in the form of distributed actuators and centrally located PLC or separated control systems connected by the communication main line, facilitates access to the data in the entire system, provided that the system components are connected hierarchically.

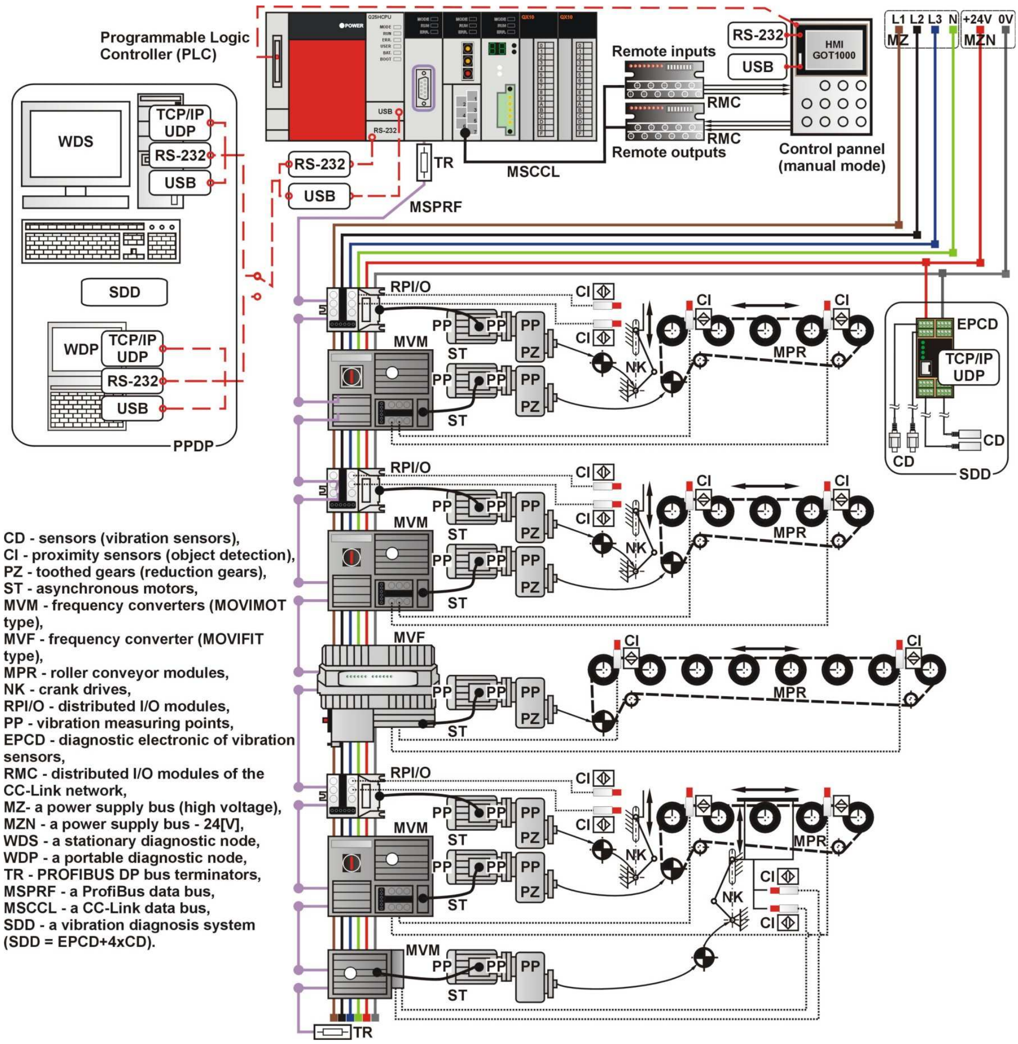

Fig. 1. Schematic view of the laboratory stand

It is necessary to present the main assumption which confirms the presented stand of authors, in the following form: entrusting to the advanced mechatronics devices of the control functions (which require a high level of reliability) allows to functionality extension at additional functions and data connected with diagnostic functions without loss of accepted quality factor.

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Consecutive parts of presented article focus at the problem of utilization of self-diagnostic functions implemented in frequency inverters for the purpose of the computer-aided identification of operating conditions.

Self-diagnostic functions of frequency inverters

Presented example of frequency inverters allows determining of a domain which could be use on the stage of the computer aided failures detection and elimination. It is worth to stress that modern mechatronic devices offer very reliable and expanded functions connected with monitoring of internal subsystems.

Utilization of inner self-diagnostic algorithms coverage by specialized electronic circuits, integrated inside mechatronic devices, brings many benefits, among others a separation of system functions (discharging of resources), shortening of time assigned to detection and elimination of identified failures, increasing of application reliability.

A result of self-diagnostic functions is given in the form of individual error code. Error codes contain 8-bits and are easy to gather by the PLC connected with the frequency inverters by the ProfiBus DP network. Additionally the PLC performs several functions at the same time:

- processing the control algorithm determined by dependences defined in accordance with the cyclogram,
- gathering the diagnostic data from frequency inverters circuits,
- checking current parameters of additional elements (like sensors, electric drives, frequency inverters, etc.) within the defined dependences (relations between states of constituent elements) determining the current state.

Table 1. Types of identified failure states with description of their sources

Ordinal number	Assigned error set	Description of sources
1.	AE-PTE	o incorrect configuration of hardware resources, o cause generated in the stage of loading of program, settings or parameters, o an overflow of a memory stack, o disturbance of the beginning or an execution of program actions, abnormalities of data conversion, settings or an active mode change.
2.	EE-HTE	o the ProfiBus DP bus failures, o incorrect matching of the hardware layer, o an abnormal work of hardware devices (the reading error, the incorrect hardware configuration, etc.), o diagnostic information, o failures of hardware components like electronic circuits, feeding interfaces, abnormal conditions of supervised units (i.e. decay of feeding voltage, phases, etc.).
3.	CE-OTE	complex relationships between identified failures belonged to the AE-PTE and EE-HTE collections

All identified failure conditions were grouped by the authors into three main domains:

- AE-PTE – application errors (connected with programming activities, configuration parameters, etc.),
- EE-HTE – hardware errors,
- CE-OTE – complex errors (coupled by conjunction of previously specified groups).

End user has not got a possibility of any influence at the form and a size of errors set notified by the internal resources of frequency inverters, because an access to the embedded circuits and functions in many cases is blocked by several methods (lack of sufficiently documentation, a resource interlocking, and a simplification of accessible functions).

A complete exploitation of advantages of AE-PTE and EE-THE collections enable continuous monitoring of values stored in variables determined control algorithm. A designer of the control algorithm decides how to use codes and how to define mutual dependences which define complex errors CE-OTE. Error codes are collected and gathered in the PLC memory. On the basis of their current values and conditions of other variables a user realizes the diagnostic inference. Each of the frequency inverter error code is treated like an independent diagnostic premise. Identification of complex errors is performed by a comparison of two (or more) simultaneously identified errors belonged to different groups within the defined relations placed in the statements of the expert system of the CCaDSoDD application. Data gathered in the CCaDSoDD expert system are transmitted in on a package in every cycle of the PLC controller.

Identified error code is sent to PLC controller in the form of one byte, transformed up to the hexadecimal number. For considered groups of frequency inverters produced by the SEW Eurodrive group the authors isolated more than 70 failures identified only by embedded self-diagnostic functions.

Taking into consideration functional constraints of considered devices the final results is satisfactory, because a defined number describes only attributes referred to the hardware subsystems (a group of diagnostic premises identified directly). Identification of residual conditions could be realized as a result of an elaboration of decision rules matched to the concrete application of distributed drives. A diagnostic inference is possible in two independent modes:

- directly on the basis of premises delivered in the form of frequency inverters error codes,
- indirectly by connection of frequency inverters error codes and additional statements implemented in the expert system.

Isolated errors (used in the direct diagnostic inference) expanded by relations connected with monitored values of the control algorithm allow to define a group of corrective actions which quantity exceed 270. The accepted inference method based on dynamic checking of a diagnosed subsystem and a failures localization model at an assumption supported by the serial inference algorithm. The structure of the described system based on the connection conforming to an automation hierarchy (Figure 2):

- electric drives and frequency inverters are placed in the lower level (a primary technology level),
- a Programmable Logic Controller performed role of a supervised unit (within the algorithm defined in the PLC memory) is placed at the group control level,
- the elaborated expert system is located on the highest level (PLC and ProfiBus DP interface mediate at the stage of data exchange between frequency inverters and the expert system).

The method of identification and definition of reciprocal dependences of complex errors were defined in accordance with the following assumptions:

- a complex error is implicated by two (or more) errors belonged to the set of AE-PTE or EE-HTE errors coupled with a conjunction condition (definition of used implications shows Figure 3),
- in case of occurrence of two or more errors from the same set (AE-PTE or EE-HTE) errors are treated as individual diagnostic premises (adequately $u_{AE\text{-}PTE}$ and $u_{EE\text{-}HTE}$); occurrence of many errors in the domain of one collection do not implicate a complex error (identified diagnostic premises take part in the inference process in accordance with defined rules in the CCaDSoDD system),
- each of errors (AE-PTE, EE-HTE) can belong to many rules implicated complex errors.

The mediate form of the inference has a lot of advantages, among others:

- possibility of unbounded forming of statements, fitted to the concrete applications,
- shortening of time connected with an elaboration of expert systems,
- an open structure and feasibility of development.

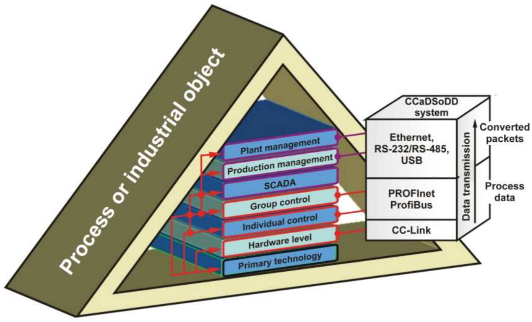

Fig. 2. Structure of the CCaDSoDD system compatible with an automation hierarchy [5]

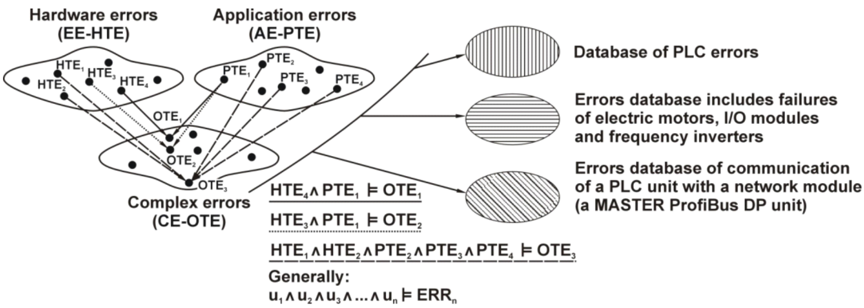

Fig. 3. A manner of definition of complex error implication (CE-OTE type), where: AE-PTE$_n$, EE-HTE$_n$⊂u, u – diagnostic premises (AE-PTE$_n$ or EE-HTE$_n$, n⊂N), ERR$_n$ – logical implication of conjunction of u premises

Implication rules are referred to all groups of diagnosed units and databases of the CCaDSoDD system. Defined relational databases are the part of the expert system. On the basis of rules the CCADSoDD system chooses descriptions of identified error, and corrective actions (steps enable a restoration of correct operating conditions). All relational databases based on the SQL language (Structured Query Language) were divided into tables; the main key is equivalent to the error code. At the stage of error identification the authors accepted a few meaningful assumptions:

- the monitoring and a collection of all data are realized within PLC tasks,
- dynamic properties of the diagnostic symptoms formation is dependent on the PLC cycle,
- in the elaborated expert system the authors do not improve a states detection on the basis of time and detection sequence of diagnostic symptoms (a packet block transfer),
- maximal time of symptom generation is equal to the PLC cycle, increased at the time connected with ProfiBus DP bus refreshing, within the equation [4] (where: $F(s_j)$ - a failures set detected by the diagnostic signal s_j, θ^2_{jk} - maximal time from the moment of occurrence of the k failure to generation of the j symptom):

$$\theta_j = \max_{k: f_k \in F(s_j)} \left\{ \theta^2_{jk} \right\} \tag{1}$$

- a set of diagnostic tests does not include elements, corresponding to symptoms with time occurrence exceeding the time predicted to a diagnosis period,
- protective functions (safety actions) of the analyzed case are executed in the time equal to the value of one PLC cycle.

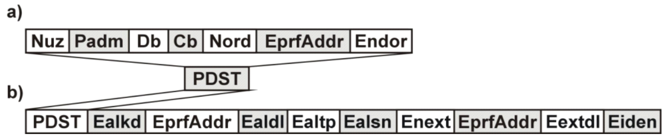

Fig. 4. View of entry error patterns of the frequency inverter: a) basic, b) extended, where: Nuz – a user name, Padm – authorization level, Db – date, Cb – current time, Nord – ordinal number of the SLAVE unit, EprfAddr – network address error, Endor – ordinal number error of the SLAVE unit, Ealkd – alarm code, Ealdl – length of the alarm information, Ealtp – alarm type, Ealsn – socket number with an active error state, Enext – extended diagnostic information code, Eextdl – data length of the extended diagnostic information, Eiden – identification number of SLAVE unit

Recording of error values are stored within defined standard (Figure 4). The pattern of error entries has been divided into two main subgroups:

- basic - main errors of the SLAVE (frequency inverter) unit,
- extended - includes all data of the basic pattern, widens the diagnostic information of the ProfiBus DP network and hardware devices.

Conclusions

Self-diagnostic functions are frequently used in states of failures removal, by the qualified staff, but an intention of the authors is turning the attention to the utilization of embedded diagnostic functions at the stage of design of the final form of applications included modern mechatronic devices. Advantages of the presented approach are meaningful, and can be summarized in several points:

- increasing of reliability of considered application,
- possibility of preparation of fault detection functions for every mechatronic unit (taking into account its functional constraints and embedded functions),
- utilization of more advanced mechatronic units allows to enlarge of amount of possible identified operating conditions by embedded subsystems,
- to the primary parameters belong, among other things: current, minimal and maximal bus cycles (detected by a industrial network module of the PLC unit), the diagnostic information, a current work status, error codes, reactive and active powers, etc.

Beyond specified advantages exists also a group of functional constraints, result in enlargement of the expenditure, connected with preparation of the control algorithm widened by memory cells which include values of diagnostic premises, elaboration of the expert system and inference rules (diversified at an angle of the concrete application).

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